Calibration Report: Eppley PIR Pyrgeometer

Summary

Calibration Date: April 20, 2010 Calibration Due Date: April 2012

Serial No.	C $V/W/m^2$	k1	k2	k3	U95
26036F3	4.185	0.06	1.003	2.9	2.94137865
27174F3	4.22	0.06	1.001	3.1	3.138591697

PMOD Equation:

$$E = \frac{U_{emf}}{C}(1 + k_1 \ T^3_B) + k_2 \ T^4_B - k_3 \ (T^4_D - T^4_B) \qquad EQN\ 1$$

Where:

E = Irradiance, W/m^2

U_{emf} = Thermopile output voltage, V

C = Sensitivity Coefficient, $V/W/m^2$

$k1,k2,k3$ = Correction factors

= Stephan-Boltzmann Constant, $5.67 \times 10^{-8}\ W/m^2\ K^4$

T_B = Output of body thermistor YSI 44031 , K

T_D = Output of dome thermistor YSI 44031, K

f = Correction factor for long wave component of direct sun if the instrument is used without a shading disk.

$T_{S\text{-}N} = (T_{SE} - T_N) + (T_{SW} - T_N)$

$T_{SE,}\ T_{N,}\ T_{SW}$ = Output of dome thermistors, southeast, north and southwest respectively, K

$$E = \frac{U_{emf}}{Cs} + T^4_B - K' \ (T^4_D - T^4_B) \qquad EQN\ 2$$

Where:

E = Irradiance, W/m^2

Cs = Sensitivity Coefficient, $V/W/m^2$

U_{emf} = Thermopile output voltage V

= Stephan-Boltzmann Constant, $5.67 \times 10^{-8}\ W/m^2\ K^4$

T_B = Output of body thermister YSI 44031, K

K' = Dome heating constant

T_D = Output of dome thermister YSI 44031, K

NREL Equation and Coefficients:

Serial No.	*k0*	*k1*	*k2*	*k3*	*Kr*	*Sigma*	*U95*
26036F3	0.0	0.243	1.003	-2.9	0.0007044	$5.6704E^{-8}$	2.976530965
27174F3	0.0	0.241	1.001	-3.1	0.0007044	$5.6704E^{-8}$	3.034613252

NREL Equation:

$$W_{in} = K_0 + K_1 * V_{TP} + K_2 * W_r + K_3 * W_{d\text{-}r}$$

Where:

- K_0, K_1, K_2 and K_3 = calibration coefficients.
- V_{TP} = thermopile outpul voltage, in micro-Volt.
- $W_r = \sigma * T_r^4$ = receiver radiation, in W/m^2,
  where:
  - $\sigma = 5.6704 * 10^{-8}$, in $W . m^{-2} . K^{-4}$
  - $T_r = T_c + k_r * V_{TP}$ = Receiver temperature, in Kelvin, and $k_r = 0.0007044$
  - T_c = Case temperature, in Kelvin
- $W_{d\text{-}r} = \sigma * (T_d^4 - T_r^4)$, in W/m^2, and T_d = Dome temperature, in Kelvin.

UUT Calibration Coefficients:

26036F3: $K_0 = 0$; $K_1 = 0.243$; $K_2 = 1.003$; $K_3 = -2.9$
27174F3: $K_0 = 0$; $K_1 = 0.241$; $K_2 = 1.001$; $K_3 = -3.1$

Uncertainty: (see attached figure for calibration data)

U_{95} = +/- 3.0 W/m^2 (w.r.t. WISG*) with Coverage Factor = 2.

**World Infrared Standard Group*

Calibration Report: Eppley PIR Pyrgeometer

Abstract

Two Eppley Laboratory, Inc. Precision Infrared Pyrgeometers (PIR) instruments were calibrated. This calibration was performed in order that the instruments comply with specifications set in the Baseline Surface Radiation Network (BSRN) Operator's Manual, V 2.1, 2005. The National Renewable Energy Laboratory's (NREL) Solar Radiation Research Laboratory (SRRL) Metrology Laboratory in Golden, Colorado performed the calibration. The calibration period was 25 March – 16 April 2010. The serial numbers of the units calibrated were 26036F3 and 27174F3.

1. Introduction

Two Eppley Laboratory, Inc. PIR's were calibrated to meet the 2005 Baseline Surface Radiation Network (BSRN) specifications. NREL's SRRL's Metrology Laboratory in Golden, Colorado completed these calibration tasks.

2. Results

Calibration results for each instrument are shown in the above summary page along with the governing equations. The use of EQN. 1 with the above tabular values is described above. The instruments at COVE use the PMOD equation as it has been the standard since COVE's inception. EQN. 2 and the associated tabular values are provided as a historical connection to the Albrecht et al. single sensitivity factor method.

The Calibration Certificates provided by NREL/SRRL describe their method of calibration. NREL provides plots that disply data using both equations (PMOD and NREL) during the calibration period.

3. Discussion

These sensors have been calibrated to permit the measurement of diffuse radiation. Global measurements involve determination of the factor *f*. The manufacturer, Eppley Laboratories, Inc., defines an uncertainty of 5%. Field data need to be examined in order to assess the standard uncertainty made by the calibrated instruments.

The single sensitivity factor calibration histories of the two sensors calibrated at NREL/ SRRL and PMOD are as follows:

26036F3

Apr. 2010	NREL	4.185	$V/W/m^2$
Mar. 2007	PMOD	3.96	$V/W/m^2$
Jan. 2002	PMOD	3.86	$V/W/m^2$
Sep. 2000	PMOD	3.61	$V/W/m^2$
Apr. 1998	PMOD	3.84	$V/W/m^2$

27174F3

Apr. 2010	NREL	4.22	$V/W/m^2$
Mar. 2003	PMOD	3.93	$V/W/m^2$
Sep. 2000	PMOD	3.77	$V/W/m^2$
Apr. 1998	PMOD	4.03	$V/W/m^2$

PIR instrument (S/N:26036F3) single sensitivity factor, *Cs*, has remained within variability of 5% or less through each of the calibrations, which did not involve physical changes to the instrument. This variability is within manufacturer stated design specifications. However, PIR instrument (S/N:27174F3) did not remian within 5% or less. This may be due to the fact that it has been 7 years since the last calibration. Hence, now this PIR is in calibration.

4. Summary

A calibration of two Eppley Laboratory Inc. PIR instruments has been completed. Data analyses have been performed. The calibration factors are presented in the summary table above and in the Calibration Certificates.

No apparent performance anomalies are indicated from the single sensitivity factor calibration history of PIR (S/N:26036F3). However, PIR(S/N:27174F3) was outside the 5% variability since its last calibration. 7 years between calibrations may explain this anomaly.

These calibration factors can be used with these two instruments after 20 April 2010.

REFERENCES

Albrecht, B., and S.K. Cox, Procedures for Improving Pyrgeometer Performance, Journal of Applied Meteorology, 16, 179-188, 1977.

Frohlich, C., and R. Philipona, Characterization of pyrgeometers and the accuracy of atmospheric longwave measurements, Ch., Betz, Applied Optics, 34(9), 1598-1605, 1995.

McArthur, J.B., World Climate Research Program, Baseline Surface Radiation Network Operations Manual, Version 2.1., 2005.

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

UUT Model:	PIR
UUT Serial Number:	26036F3
Traceability:	WISG *, using PIRs: 31197F3
Calibration Period:	25 March to 16 April, 2010
Environmental Conditions:	Outdoors/variable conditions

Equation:

$$W_{in} = K_0 + K_1 * V_{TP} + K_2 * W_r + K_3 * W_{d-r}$$

Where:

- K_0 , K_1 , K_2 and K_3 = calibration coefficients.
- V_{TP} = thermopile output voltage, in micro-Volt.
- $W_r = \sigma * T_r^4$ = receiver radiation, in W/m^2,
  where:
  - $\sigma = 5.6704 * 10^{-8}$, in $W . m^{-2} . K^{-4}$
  - $T_r = T_c + k_r * V_{TP}$ = Receiver temperature, in Kelvin, and $k_r = 0.0007044$
  - T_c = Case temperature, in Kelvin
- $W_{d-r} = \sigma * (T_d^4 - T_r^4)$, in W/m^2, and T_d = Dome temperature, in Kelvin.

UUT Calibration Coefficients:

$K_0 = 0$; $K_1 = 0.243$; $K_2 = 1.003$; $K_3 = -2.9$

Uncertainty: (see attached figure for calibration data)

$U_{95} = \pm 3.0\ W/m^2$ (w.r.t. WISG *) with Coverage Factor = 2.

* *World Infrared Standard Group*

Calibrated by :	Ibrahim Reda	**QA by:**	Daryl Myers
Title:	Senior Scientist II	**Title:**	Senior Scientist II
Signed:		**Signed:**	
Date:	04/20/2010	**Date:**	04/20/2010

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

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Title:	Senior Scientist II	**Title:**	Senior Scientist II
Signed:		**Signed:**	
Date:	04/20/2010	**Date:**	04/20/2010

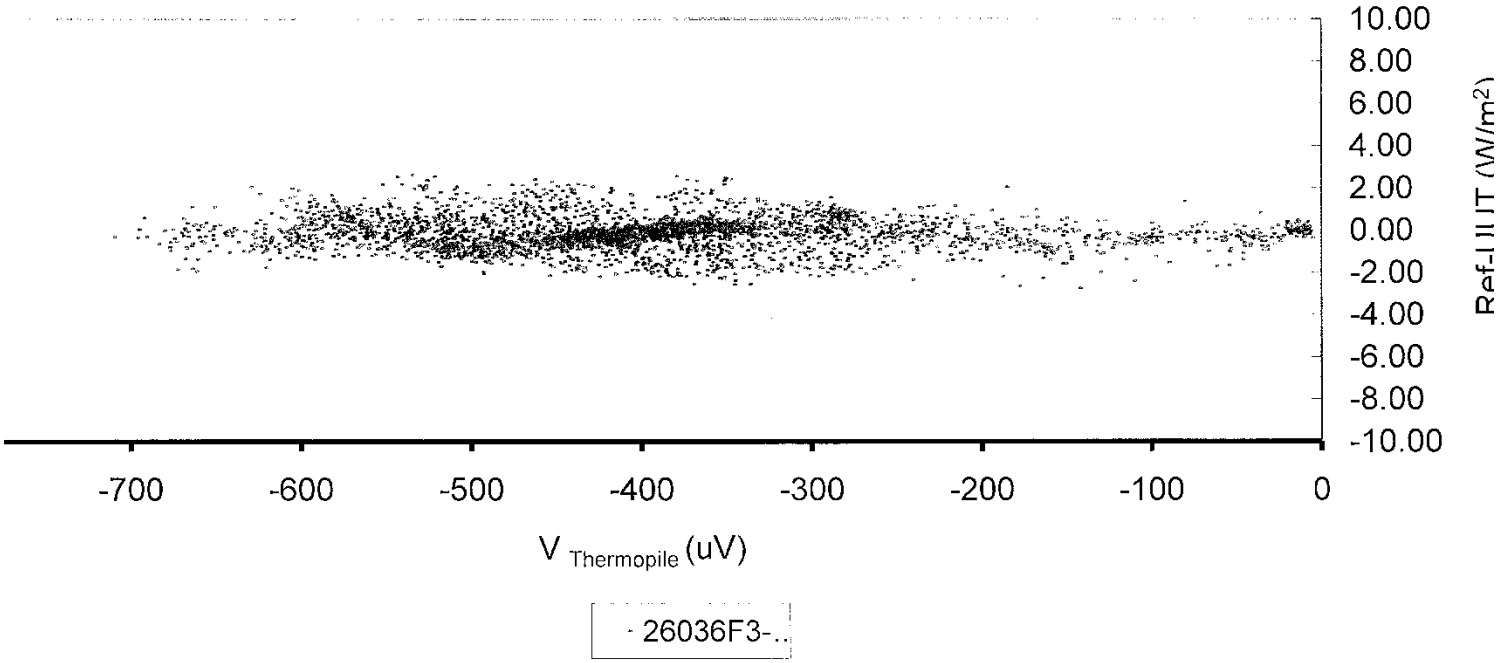
NREL equation	31197F3	26036F3	27174F3
K0	4.03	0	0
K1	0.241	0.243	0.241
K2	0.991	1.003	1.001
K3	-2.61	-2.9	-3.1
Kr	0.0007044	0.0007044	0.0007044
Sigma	5.6704E-08	5.6704E-08	5.6704E-08
U95	1.8	2.976530965	3.034613252
PMOD equation			
C	4.25	4.185	4.22
K1	0.06	0.06	0.06
K2	1.0025	1.003	1.001
K3	2.6	2.9	3.1
U95	1.8	2.94137865	3.138591697

Reda, 4/20/2010

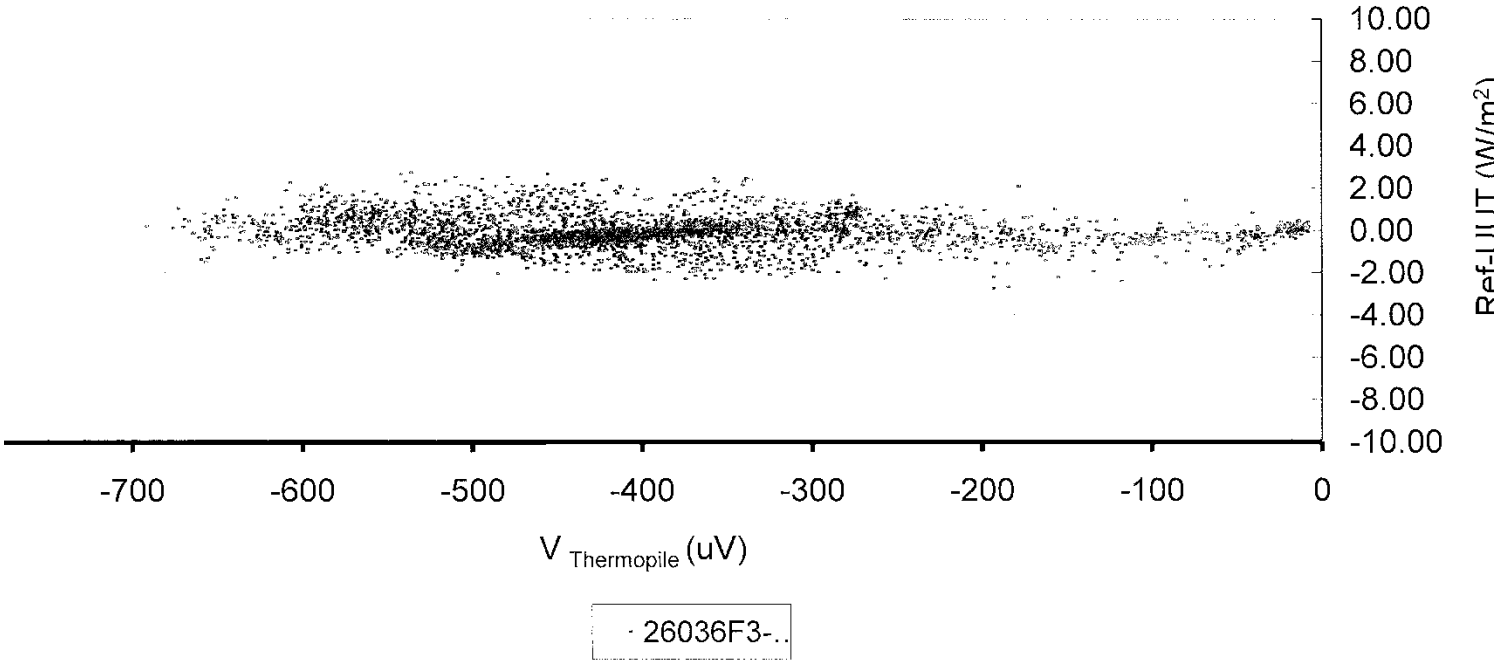
1OD Equation:

$= (V/C)*(1+K1*Sigma*T_c^3)+K2*W_c - K3*(W_d - W_c)$

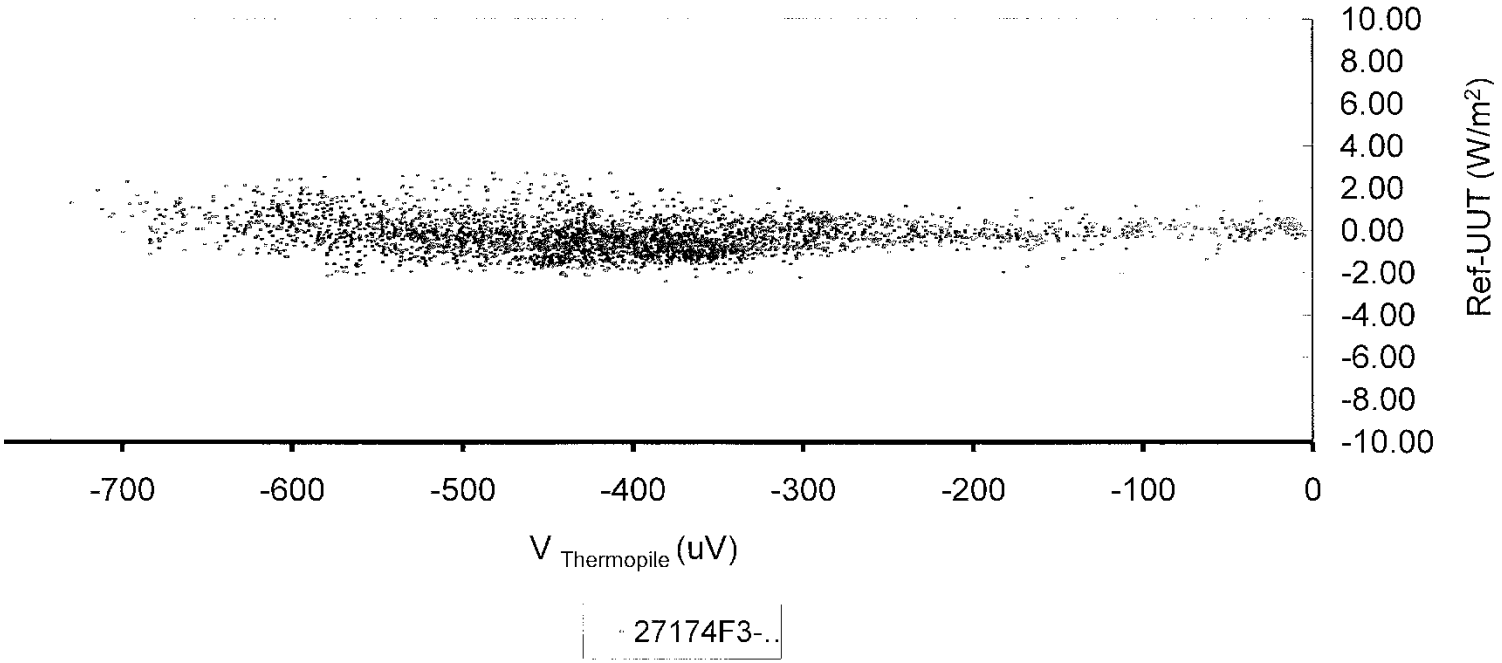
Outdoor Reference IR irradiance minus the irradiance measured by unit under test from 3/25 to 4/16/2010 using NREL equation



Outdoor Reference IR irradiance minus the irradiance measured by unit under test from 3/25 to 4/16/2010 using PMOD equation



Outdoor Reference IR irradiance minus the irradiance measured by unit under test from 3/25 to 4/16/2010 using NREL equation



Outdoor Reference IR irradiance minus the irradiance measured by unit under test from 3/25 to 4/16/2010 using PMOD equation